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**Abstract**

We have characterized the Advanced Radiographic Capability injection laser system and demonstrated that it meets performance requirements for upcoming National Ignition Facility fusion experiments. Pulse compression was achieved with a scaled down replica of the meter-scale grating ARC compressor and sub-ps pulse duration was demonstrated at the Joule-level.

## Introduction

Dynamic x-ray radiography of Inertial Confinement Fusion (ICF) implosions is a core requirement for diagnosing key experimental parameters in the National Ignition Campaign. The Advanced Radiographic Capability (ARC) project is designed to produce energetic x-rays in the range of 10-100 keV with high yield for backlighting of NIF targets[1-3]. The ARC laser system will occupy 4 of the 192 NIF beamlines split into 8 beams delivering laser pulses with adjustable pulse durations from ~1 ps to 50 ps at the kilo-Joule level. The projected peak focused intensity will be above $10^{18}$ W/cm$^2$. Adjustable time delays between the 8 beams enable X-ray "motion-picture" capture with tens-of-picoseconds temporal resolution during the critical phases of an ICF shot. ARC will also support a variety of other high energy density experiments and fast igniter studies on NIF. Full scale fast ignition on NIF will require high-energy (tens of kJ), short pulse duration (~10 ps), and small focal spot size (tens of microns).

## ARC architecture

ARC is a Petawatt-class, chirped pulse amplification (CPA) system implementing eight meter-scale four-grating compressors to deliver compressed pulses just before focusing into the NIF
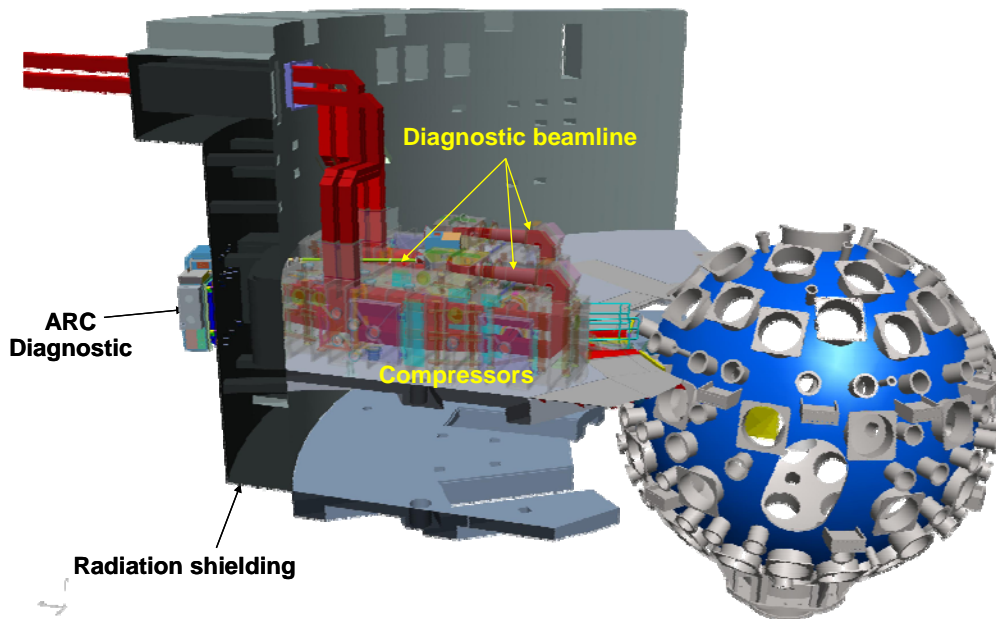


Fig. 1: The Advanced Radiographic Capability on NIF utilizes up to 4 beamlines of NIF. The picture shows the 8 ARC compressors, housed in two vacuum compressor vessels next to the NIF target chamber. The diagnostic package for ARC is located behind the radiation shielding.

target chamber [Fig. 1]. ARC will operate in a split beam configuration, dividing each NIF aperture into two subapertures that fit on pairs of side-by-side, 91 cm wide, compressor gratings. This split-beam architecture produces eight, high-intensity, short pulses from a quad of NIF beamlines. The short pulse is generated in a mode-locked fiber oscillator, ensuring stability and robust operation in a compact geometry[4]. Pulses are stretched for CPA in a chirped-fiber-Bragg grating (CFBG), specially designed as the conjugate of the calculated dispersion of the overall laser system. After further amplification the beam is split into two, and launched into two small bulk grating pre-compressors, functioning as pulse width controllers (PWC). By adjusting the group velocity dispersion of each pulse, these PWCs will control the temporal pulse width at the final ARC compressor output from the sub-ps transform limit to 50 ps. The pulses are then routed by a transport fiber and amplified by a Yb-doped fiber up to 1 microJoule just prior to injection into bulk Nd:Glass regenerative amplifiers. To compensate for gain-narrowing, we added a birefringent, gain-flattening filter to the regen cavity, extending the bandwidth from 2.2 nm to to 4.5 nm at the output. The two regen outputs are spatially shaped, apodized and combined as two ARC sub-apertures whose outer perimeter matches a NIF beam at the input of the 4-pass rod amplifier. The shaping is designed to pre-compensate the spatial gain profiles in the NIF rod and slab amplifiers to produce a pair of rectangular, flat-top, near-field profiles at the NIF amplifier chain output. The regen outputs are then combined and shaped into a pair of subapertures in a Split Beam Injection (SBI) module. The combined shaped beam is then further amplified in a 4-pass Nd:Glass rod amplifier, producing up to 6 Joules in a spatial format tailored for direct injection into the NIF main amplifiers. The main amplifiers will amplify each individual subaperture to ~1 kJ (dependent on pulse duration). Two vacuum vessels containing 4 compressors each compress the pulses; the output pulse duration is dependent on the PWC setting. Space constraints in the NIF target bay required a compact folded compressor design[2]. There are actually four pairs of 4 grating compressors: one grating in the pair is illuminated by one ARC sub-aperture and the second grating of the pair is illuminated by the other sub-aperture. Each grating in the pair has slightly different groove densities to reduce crosstalk between the subaperture beams. Each of the eight compressors employs four different 91cm x 45 cm multi-layer dielectric diffraction gratings, produced by LLNL[5].

Four major contributions to group velocity dispersion need to be carefully balanced: Material dispersion of several tens of meters of glass, CFBG, PWC, and the compressor. Since the system does not allow adjustment of the dispersion among different NIF apertures, alignment of the 8 ARC compressors has to be performed such that the overall residual group delays are less than 1 ps across all subapertures to meet specifications. An RF phase-shifting technique[6] will be used to precisely measure the group delay of each individual subsystem and to match the dispersion characteristics of each individual compressor.

## ARC frontend test facility

The performance of ARC relies critically on the front-end performance and the dispersion pre-compensation in the system. We have built and qualified the ARC front-end prototype (up to the 4-pass Joule level amplifier) in an offline facility. We use this test facility to demonstrate dispersion balance, measure temporal fidelity, and characterize the near- and far-field spatial profiles for the compressed ARC front end. We also use this facility to provide real data for our propagation and energetics models that predict overall performance of the ARC system. In order to test compressed pulses, we constructed a scaled down compressor designed with the same calculated dispersion values to demonstrate our dispersion management scheme. After installation, we measured the group delay (GD) dispersion of the compressor using the phase shifting technique described in [6]. Earlier measured GD-data of the fiber front was used to design the PWC. We also test various temporal diagnostics on this test facility that will be used for recording shot data at the ARC output. The temporal diagnostics include an ultra low-energy (picoJoule), scanning cross-correlator, a single-shot FROG (frequency resolved optical gating) device allowing detection of pulses up to 5 ps in duration, and a homebuilt multi-shot scanning FROG with ultra-wide temporal window (several tens of ps and true ~1:400 dynamic range).We also record for each shot a high resolution spectrum to validate our results.

## Results

Using the birefringent intracavity filter in the regen, the spectral width of the laser output was optimized. Gain narrowing in the pre-amplifier module using a LHG-8 rod is compensated by broadening and shifting the regen spectrum to the blue. The spectrum was centered at 1052.6 nm and broadened up to 4.5 nm. We set the PWC grating angle of incidence, AOI, and slant distance to the nominal
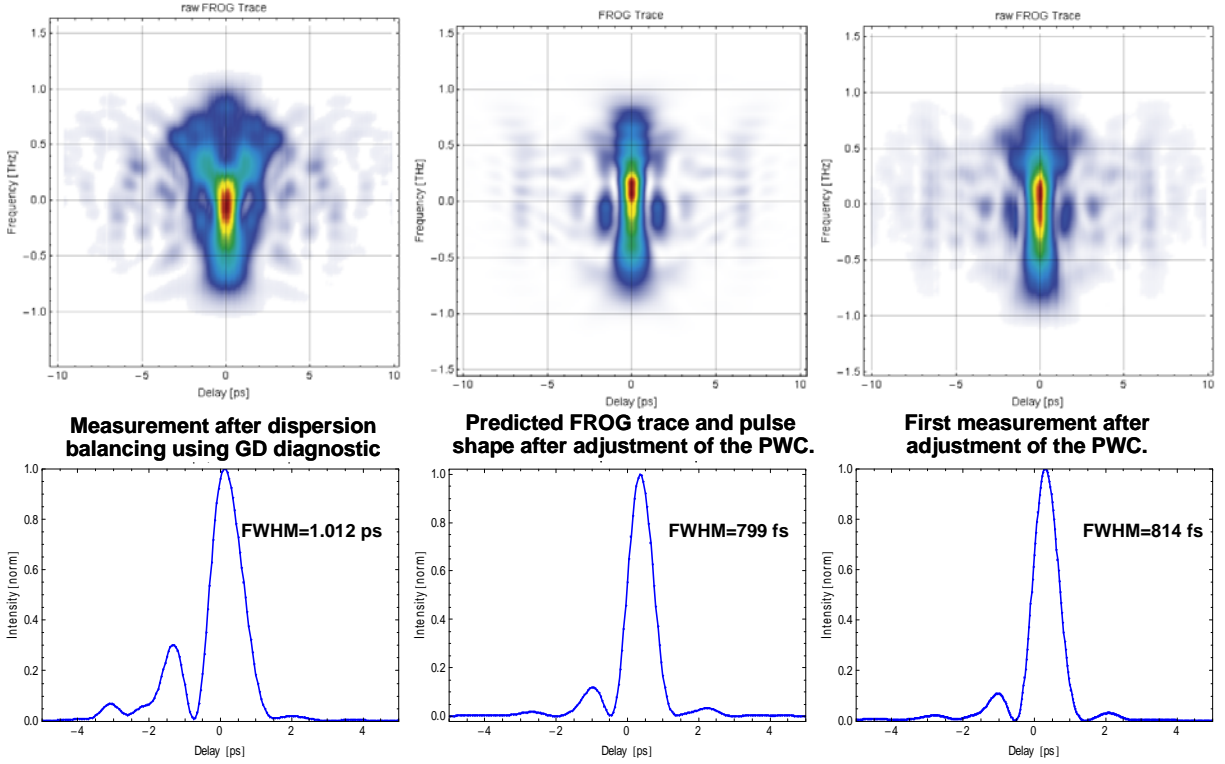
**Fig. 2: (a) FROG trace of the initial measurement, where only the group delay diagnostics and the autocorrelator was used to analyze and balance dispersion. (b) FROG trace and predicted pulse shape based on data from (a) with modeled re-adjustment of the pulse width controller. (c) Experimental validation of the predicted pulse shape after changing angle and slant distance of the pulse wifth controller.**

values predicted by our group delay diagnostic measurements and dispersion balance model. We measured the compressor output pulse width with a single-shot autocorrelator while optimizing the PWC slant distance for the shortest autocorrelation. A change of ~2mm in slant distance from the model prediction was necessary to produce the shortest pulse on the autocorrelator Next we made a high dynamic multishot FROG measurement, and performed a high resolution, precision FROG analysis based on principal components gerneralized projections[7] yielding E(t, λ). We mimimized the RMS deviations of the GD across the spectrum using the angle of incidence and slant distance of an analytic Treacy formalism as parameters. The obtained values were applied to the PWC and the measurement repeated. Fig. 2b shows the predicted FROG trace and pulse shape based on data obtained in (a) with the change in dispersion based on the Treacy model for the PWC. After changing angle of incidence and slant distance of the PWC according to the model a nearly transform limited pulse duration of 814 fs was achieved. The remaining small pre-pulse ~1.3 ps ahead of the main pulse is attributed to the group delay ripples in the CFBG and does not affect the overall performance of ARC.

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